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DOI: https://doi.org/10.1121/1.2437848

Originally published at:
Schmuziger, N; Brechbuehl, M; Probst, R (2007). Acoustic measures of low-frequency noise in extended high-frequency audiometry. Journal of the Acoustical Society of America, 121(3):EL120-EL124.
DOI: https://doi.org/10.1121/1.2437848

Acoustic measures of low-frequency noise in extended high-frequency audiometry

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Abstract: A very high signal-to-noise ratio is required for equipment designed for extended high-frequency audiometry because listeners with almost no hearing ability in the extended high-frequency range may have normal hearing sensitivity in the lower frequencies. Two commercially available systems designed for pure-tone audiometry were evaluated both in the conventional and extended high-frequency range. Unwanted lower frequency signals greater than the noise floor occurred predominantly at presentation levels of approximately 110 dB SPL or higher. Test tones in the extended high-frequency range should be restricted to levels that are not associated with lower frequency noise.

PACS numbers: 43.80.Vj, 43.58.−e [BLM]
Date Received: December 1, 2006 **Date Accepted:** January 8, 2007

1. Introduction

Extended high-frequency audiometry is a suitable method for the early detection of ototoxicity (e.g., Fausti *et al.*, 1999). Several audiometers are available that include the extended high-frequency range. A very high signal-to-noise ratio is required for such equipment because listeners with almost no hearing ability in the extended high-frequency range, particularly for the highest frequencies, may have normal hearing sensitivity for the lower frequencies. According to the specifications of the International Electrotechnical Commission (IEC), "no test subject shall detect any unwanted sound from the transducer coinciding with the presentation of the test tone, even at the maximum setting of the hearing level control (IEC, 1994)."

Reference equivalent threshold sound pressure levels (RETSPLs) correspond to the mean/modal hearing thresholds of a "sufficiently large number of ears of otologically normal persons of both sexes aged between 18 and 30 years," according to IEC 60645-1 (2001). They are lower than 10 dB SPL in the frequency range from 0.5 to 6 kHz and increase up to 56 dB SPL at 16 kHz using the circumaural earphone HDA 200 from Sennheiser (ISO 389-5, 1998). Hearing thresholds of patients receiving aminoglycosides are often poorer than these RETSPLs, particularly in the extended high-frequency range, considering that presbycusis affects the highest frequencies first. Therefore, test tones in the extended high-frequency range have to be presented often near to the maximum setting of the hearing level control, particularly at 14 and 16 kHz. Such sound pressure levels are typically around 100 to 120 dB SPL, making unwanted low frequency noise or sound more likely.

In the literature, only a few incidental remarks may be found concerning the issue of the effects of low-frequency noise on thresholds in the extended high-frequency range. Frank

(1990) reported that unwanted sounds below the test frequencies were not detected within the 80-dB dynamic range of the signal analyzer testing tone levels of 120 dB SPL at frequencies of 10, 12, 14, 16, 18, and 20 kHz using a commercially available Beltone 2000 audiometer (Beltone Electronics). Unwanted sound or signals above the test frequencies were present at harmonics of these frequencies and were at least 35 dB below the presentation level of the test tones.

In evaluating equipment for an experiment on the effects of noise exposure (Schmuziger *et al.*, 2004), the first author noted that there was noise present in the signals generated by some equipment. Based upon this observation, a survey of commercially available equipment used for testing in the conventional and extended high-frequency range was undertaken. The low-frequency noise present during the output of signals in the extended high-frequency range was measured in two audiometers that were selected because they were available commercially on the local market at the time of the study. This article discusses the results of the survey and their clinical implications.

2. Material and methods

2.1 Audiologic equipment

Two commercially available systems designed for pure-tone audiometry both in the conventional and the extended high-frequency range were evaluated: Madsen Itera II (GN Otometrics, Denmark) and GSI 61 (Grason-Stadler, United States of America). They are diagnostic two-channel audiometers that, according to the manufacturers, meet or exceed the international standard for equipment for extended high-frequency audiometry according to IEC 60645-4 (1994). Frequencies in the extended high-frequency range included 8, 9, 10, 11.2, 12.5, 14, and 16 kHz according to ISO 389-5 (1998). According to IEC 60645-4 (1994), the frequency of 8 kHz is considered to be both the highest frequency in the conventional range and the lowest frequency in the extended high-frequency range. Additionally, the GSI 61 has an option for 18 and 20 kHz.

2.2 Calibration

Audiometers, equipped with Sennheiser HDA 200 earphones, were calibrated according to the regulations of the Swiss Federal Office for Metrology and according to ANSI S.3.6-1996 (1996), ISO 389-1 and 389-5. Reference equivalent threshold sound pressure levels for 18 and 20 kHz on the GSI 61 audiometer were specified by the manufacturer.

2.3 Sound level measurements

Sound level measurements were performed by Norsonic Brechbuehl AG, Switzerland, in a double-walled sound treated booth. Only one channel/headphone combination was evaluated for each audiometer. The selection of this combination was counterbalanced across equipment. Measurements were made using an IEC 318 artificial ear, which includes a Brüel and Kjaer (B&K) 4153 artificial ear with a B&K type 1 flat plate adaptor (DB0843), and a B&K 4134 $\frac{1}{2}$-in. microphone. The artificial ear was connected to a 01 dB-Metravib Orchestra signal analyzer with a dynamic range of more than 100 dB with the option for signal analysis by real-time narrow band fast Fourier transform (FFT, 4096 points, Hanning Window).

Tones were presented initially at the maximum output of each audiometer, which was predetermined by the manufacturer and reduced in 5-dB steps. Median maximum output levels for all test frequencies in the extended high-frequency range were 109 dB SPL (range: 106–115) for the GSI 61 and 116 dB SPL (range 101.6–126) for the Itera II. The results were stored on the hard disc of the analyzer for later analysis on the PC using the dBFA software suite from 01 dB-Metravib.

3. Results

Unwanted lower frequency signals at audible levels were more prominent for the Madsen Itera II than for the GSI 61. All of the lower frequency signals were audible to the first author, whose

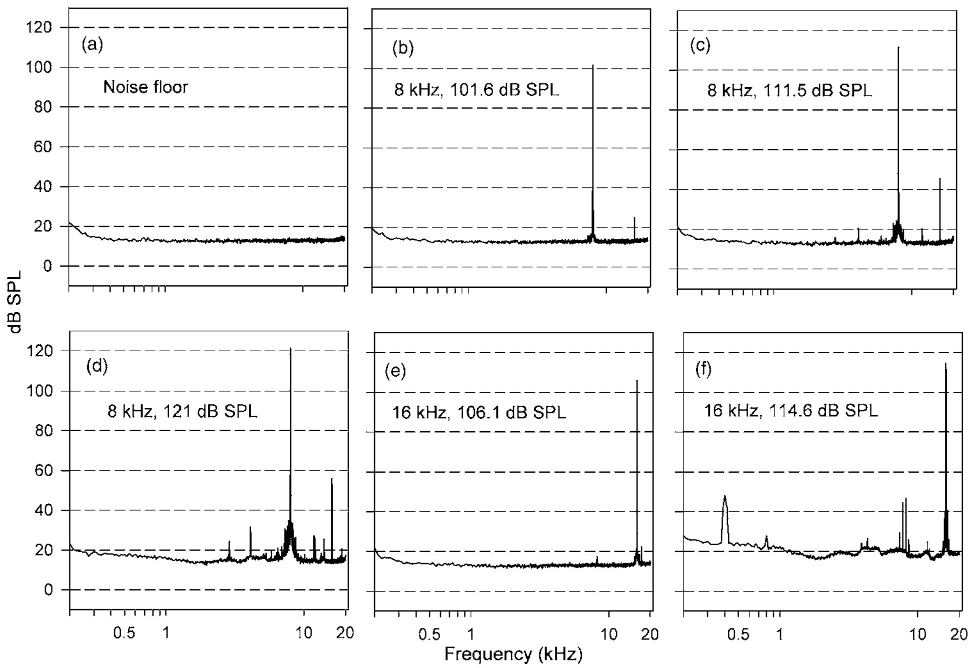

Fig. 1. Spectral analysis of the acoustic output of the Madsen Itera II generating 8- and 16-kHz tones at different levels specified in the title of each spectrum. The noise floor of the audiometer (signal analysis without test tone) is depicted in panel (a).

audiometric thresholds are plotted in Fig. 2. The noise floor from the audiometers was approximately 13 dB SPL for frequencies above 0.3 kHz and is shown in Fig. 1(a) for the Madsen and in Fig. 2(a) for the GSI.

3.1 Madsen Itera II

Unwanted lower frequency sounds occurred particularly at 8 and 16 kHz. Unwanted signals below a test frequency of 8 kHz presented at approximately 121 dB SPL were present at harmonics of 4.1 kHz with a level of 31.6 dB SPL. Moreover, peaks occurred at 2.9 and 0.3 kHz

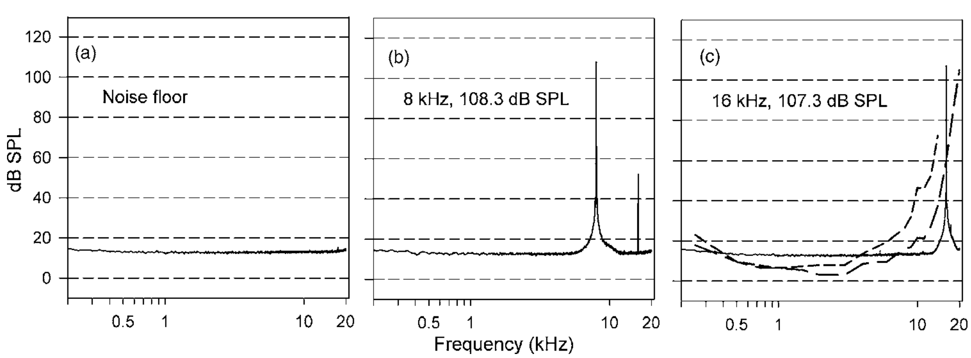

Fig. 2. Spectral analysis of the acoustic output of the GSI 61 generating 8- and 16-kHz tones at different levels specified in the title of each spectrum. Gray medium-dashed line: Hearing threshold levels of the first author (dB SPL). Dark gray long-dashed line: RETSPLs for 0.25–20 kHz. The noise floor of the audiometer is depicted in panel (a).

with levels of 24.3 and 19.3 dB SPL, respectively [Fig. 1(d)]. Reducing the level of the signal to 111.5 dB SPL or lower reduced the occurrence of these unwanted signals to a few dB over the noise floor, as depicted in Figs. 1(b) and 1(c).

A presentation level of 114.6 dB SPL at 16 kHz was associated with unwanted signals of close to 50 dB SPL at the harmonic frequency of 8 kHz, but such signals were also present near 0.4 kHz, as shown in Fig. 1(f). These unwanted signals could not be detected above the noise floor when the level was reduced to 106.1 dB, as demonstrated in Fig. 1(e).

3.2 GSI 61

No unwanted signals could be measured for any frequencies with our equipment, even at the maximum output of the audiometer. However, the listening check by the first author revealed weakly audible low-level noise at lower frequencies when a 16-kHz signal was presented at 107.3 dB SPL, 18 kHz at 109.1 and 113 dB SPL, and 20 kHz at 115 dB SPL. The audiometric thresholds of the first author and RETSPLs are plotted in Fig. 2(c), along with the output of the signal analyzer for a 16-kHz tone at 107.3 dB SPL.

4. Discussion and conclusions

The International standard IEC 60645-4 (1994) for equipment for extended high-frequency audiometry states that "No test subject shall detect any unwanted sound from the transducer…, even at maximum setting of the hearing level control." Because many listeners with almost no hearing ability at the highest frequencies, particularly at 14 kHz and above, have normal hearing sensitivity for the lower frequencies, these requirements are very difficult to achieve for commercially available clinical audiometers. This is a serious limitation for the clinical use of extended high-frequency audiometry because false-positive responses may occur. The most common clinical use of extended high-frequency audiometry is monitoring of potential aminoglycoside-induced hearing loss, which typically affects hearing first in the highest frequency range with later progression to the lower frequency regions (Fausti *et al.*, 1999). Thresholds in the extended high-frequency range potentially could be underestimated because a patient might be responding to lower frequency noise produced by the hardware. Therefore, perception of lower frequency noise or off-frequency signals could result in missing early signs of ototoxicity.

Spectral analysis of the output of the audiometer does not guarantee that the requirements according to IEC 60645-4 (1994) are met in all cases, because the dynamic range of most analyzers is not wide enough to cover the full range of differences between extended high- and low-frequency hearing. The unwanted signals may not be detectable above the noise floor of the audiometer. The signal analyzer used in this study had an excellent dynamic range of more than 100 dB, which is greater than analyzers available for clinical use (Frank, 1990). Nevertheless, our results with the GSI 61 audiometer demonstrated that even when no unwanted signals were measured above the noise floor of the audiometer, some low-level noise at lower frequencies was audible by the first author performing listening checks when test tones at 16 kHz and above were presented at the maximum output of the audiometer.

Unwanted lower frequency signals or off-frequency signals occurred more often for the Madsen Itera II than for the GSI 61, probably because the maximal output levels of the test tones were generally higher and less restricted for the Madsen. The output levels of test tones in the extended high-frequency range should be restricted to meet the requirements of IEC 60645-4 (1994). According to IEC 60645-1 (2001), "objective acoustical measurements may be impracticable for testing for the presence of unwanted sound from the audiometer. Therefore, subjective tests shall be performed using at least two otologically normal test subjects whose hearing threshold levels shall not exceed 10 dB for the test frequencies 250 Hz to 8 kHz." Similar subjective tests could be advantageous for extended high-frequency audiometry, using otologically normal test subjects with normal hearing in the conventional frequency range and presumably impaired hearing in the extended high-frequency range. Stelmachowicz *et al.* (1989) obtained auditory thresholds in the 8- to 20-kHz range from 240 subjects ranging in age from 10 to 60 years and found that the largest changes in sensitivity with age occurred between

40 and 59 years. Considering their results, it seems reasonable to assume that anyone over the age of 40 years is likely to have hearing loss in the extended high frequencies. Providing that such subjects have normal hearing in the conventional frequency range, they would probably be suitable to participate in such subjective tests. Subjects with hearing loss in the extended high-frequency range are more suitable than subjects with normal hearing in this frequency range because low-frequency sound or noise will usually only occur at test tone levels near the maximum output of the audiometer and one would not want to expose subjects with normal hearing to such high levels. Even more importantly, such test tone levels well above the individual's threshold could mask unwanted lower-frequency sound.

Manufacturers of equipment for extended high-frequency audiometry should be responsible for performing the subjective tests needed to check the accuracy of their equipment and potentially to restrict the maximum output of their audiometers to levels that are unlikely to produce unwanted lower-frequency sound. Moreover, such subjective tests should be regularly performed during the clinical use of such equipment, at least at the time of regular calibrations.

Further efforts are needed by the manufacturers to design commercially available audiometers for extended-high-frequency audiometry with improved signal-to-noise ratio. The introduction of a steady background of low-level noise restricted to the conventional frequency range to the test earphone could be helpful for masking the off-frequency energy or unwanted sound. It could prevent listeners from responding to these low-frequency sounds when high-frequency test signals are presented. Further studies could be advantageous to determine the effective dynamic range of the measurement system combining acoustical measurements of the test tones and masking studies with noise restricted to the conventional frequency range.

Acknowledgments

This study was supported by grants from the Society of Hearing-Impaired People of Basel, Switzerland. Dr. Frances P. Harris provided very helpful comments on an earlier version of this manuscript. The authors gratefully acknowledge Albert Stücheli from Diatec, Switzerland, and Dr. Martin Kompis, Head of the Audiology from the Department of Otorhinolaryngology, University Hospital Berne, Switzerland, for their collaboration.

References and links

American National Standards Institute (**1996**). "American National Standard Specification for Audiometers," ANSI S3.6 (ANSI, New York).

Fausti, S. A., Henry, J. A., Helt, W. J., Phillips, D. S., Frey, R. H., Noffsinger, D., Larson, V. D., Fowler, C. G. (**1999**). "An individualized, sensitive frequency range for early detection of ototoxicity," Ear Hear., **20**, 497–505.

Frank, T. (**1990**). "High-frequency hearing thresholds in young adults using a commercially available audiometer," Ear Hear., **11**, 450–454.

International Electrotechnical Commission (**1994**). "Audiometers-Part 4: Equipment for extended high-frequency audiometry," IEC 60645-4 (IEC, Geneva).

International Electrotechnical Commission (**2001**). "Electroacoustics—Audiological equipment - Part 1: Pure-tone audiometers," IEC 60645-1 (IEC, Geneva).

International Organization for Standardization (**1998**). "Acoustics-Reference zero for the calibration of audiometric equipment-Part 1: Reference equivalent threshold sound pressure levels for pure tones and supra-aural earphones," ISO 389-1 (ISO, Geneva).

International Organization for Standardization (**1998**). "Acoustics-Reference zero for the calibration of audiometric equipment-Part 5: Reference equivalent threshold sound pressure levels for pure tones in the frequency range 8 kHz to 16 kHz," ISO/TR 389-5 (ISO, Geneva).

Schmuziger, N., Probst, R., and Smurzynski, J. (**2004**). "Test-retest reliability of pure-tone thresholds from 0.5 to 16 kHz using Sennheiser HDA 200 and Etymotic Research ER-2 earphones," Ear Hear., **25**, 127–132.

Stelmachowicz, P. G., Beauchaine, K. A., Kalberer, A., and Jesteadt, W. (**1989**). "Normative thresholds in the 8- to 20-kHz range as a function of age," J. Acoust. Soc. Am. **86**, 1384–1391.